PLEA 2017 EDINBURGH
Design to Thrive

Mind the Gap; Methodology Discussion of the Extraction and Analysis of Pilot Phase Data to Generate Multi-Configuration Household Behavioural Profiles

AbdelRahman A.I.M. Aly[1], Amira ElNokaly[1], Glen Mills[1]

[1]School of Architecture & Design, University of Lincoln, Lincoln, United Kingdom

Abstract: This paper constitutes the conclusion of a three-month pilot study, concluding March 2017, performed in a CfSH level 5 housing projects in Lincolnshire, UK. The study uses purpose designed activity and occupancy logs, climate tracking and monitoring of interior environment through the use of data loggers. The research's final output uses occupancy tracking by introducing self-observation and its translation to energy consumption by its integration into multiple occupancy calculation methodologies to investigate these results within the post-pilot study phase. The pilot study constitutes the development of these methods according to each house's occupants and the research objectives. The study aims at generating multi-configuration household behavioural profiles through extracting a comprehensive full set of data, including room functions, activities and factors that contribute to energy consumption by balancing the use of logs and participant comfort. The research undertakes a bottom-up survey, assessing consumption information of frequently used equipment in the house and calculating variable total consumption in accordance with the occupancy and activity logs. In addition, the use of an initial semi-structured interview that was undertaken to address the phenomenological causes that underline the observed behaviour, as well as account for non-quantifiable factors of behaviour. The findings of this study have shown patterns of behaviour that are atypical of usual design assumptions as well as a variety of household combinations that interact uniquely with their buildings.

Keywords: Behavioural Profiles; Performance Gap; Occupancy log; Code for Sustainable Homes (CFsH)

Introduction

Agencies in the UK began with rolling out regulations to affect citizens' energy consumption. By adjusting how houses are constructed and how users interact with their building through cost manipulation (Odeyale etal, 2013; Warren, 2014) and enforcing regulations for planning and construction. After the development of Eco-Homes and its later iteration, Code for sustainable Homes in 2007, in March 2015 BRE announced the phasing out of CfSH and the use of the previously known as code level four as the base level for construction until 2016 (GOV, 2015; Department for Communities and Local Government, 2015). However measured performance post-occupation needed improvement and this caused the surfacing of PROBE studies 1995-2002 by CIBSE followed by Building Performance Evaluation funding (Tse and Colmer, 2014).As of writing this paper in 2017, housing standards are at a tipping point following the new optional building regulations which still use the previous version of SAP and the optional ability to construct houses based on any of the international or national standards such as the newly developed Home Quality Mark (HQM and BRE, 2015).During that transitional shift in regulation, the final reports for the building performance evaluation program and the performance gap studies by InnovateUK and Zero Carbon Hub (ZCH) as well as partner universities and industry specialists were published ending a phase of "proving the existence of the performance gap" and in a way, initiating the age of bridging the gap during the transitional and recommendations period (Tse and Colmer, 2014; ZCH, 2015; Digital Catapult, 2016; Pannell, 2016)). This change in regulation left the

industry with a number of projects that were still under construction and ones that already exist with a set of issues that contribute to the performance gap as summarized by the ZCH end of term report (Zero Carbon Hub, 2013). Since the newly introduced Home Quality Mark has to conform to the Standard Assessment Procedures' (SAP) regulations included in Part L of the planning permissions process (HQM and BRE, 2015), it still faces the same issue of calculating user behaviour. A problem unlikely to change since the methodology implemented within SAP existed in CfSH, will exist part of building regulations post-2016 standards' review and will exist when Home Quality Mark is fully launched. Thus it remains a persistent issue for researchers, designers and assessors to work towards solving this problem.

Within the context of BREEAM building codes (CfSH and the upcoming HQM), energy calculations are accounted to achieving a reduction in emissions based on the calculations done within the SAP's technical document/ application. Said calculations, mainly within SAP's occupancy calculation (Henderson and BRE, 2008) and tables 9 within the SAP document (ref) regarding space heating which disregard personal comfort and variations in ambient space temperature (BRE and DECC, 2014), whilst serving as a benchmark in the design process, upon post-occupancy evaluation, the benefit of a probabilistic model would be needed for comparison to validate the real life trend against calculations and thus be able to decide whether the performance gap was due to short-sightedness within SAP or if users' behaviour was too unpredictable for a fixed or dynamic model to estimate (Richardson et al., 2010; Gruber and Prodanovic, 2012; Blight, 2015).

Occupant behaviour is attributed to a number of theories, following or a mixture of theories of planned behaviour Ajzen, 2011, and environmental physical probabilism (Kaiser and et al, 1996), both of which were observed through the methodologies to be discussed in the following sections. Starting at a macro scale with the choice of living in an eco-house by following an assumed theory of self-selection (Michelson, 1977). How user behaviour within their dwelling can be recognized through the models of planned behaviour; addressing the premise that behavioural beliefs, normative beliefs and perceived control over their personal comfort by being able to alter their habitat (Borden and Schettino, 1979; Ajzen, 2011; Blight, 2015). Finally, complimented by probabilism (Kaiser and et al, 1996), a midway point between environmental deterministic and possibilistic factors. The assumption that users are likely to perform actions due to a deterministic environmental factor, however their personal comfort, external criteria and free choice determines whether or not they are likely to do it (Borden and Schettino, 1979).

Examples of these factors that have been previously established are internal and external climate; predictive mean vote of personal comfort; architectural layout and spatial functions; occupancy patterns; age factors; employment and associated routine. The range of factors that operate within these theories are impractical to empirically quantify as they change depending on the conditions surrounding the subjects as well as flow with their own perception and experience of space (Parys, Saelens and Hens, 2011; ElNokaly & ElSeragy, 2012). Thus the researcher operated on the concept that behaviour of residents of eco-houses who share the values of self-selection and planned behaviour would have similar operational norms, whilst factors such as their age, employment and occupancy patterns would vary due to probabilistic factors that could not be isolated but perhaps regressed into consumption trends that would serve as a comparative baseline for design or post-occupancy evaluation. However, a limitation to this research is to account for the variable occupant numbers per dwelling, their employment and their age would create a variation in results that cannot be considered statistically significant on a large scale without acquiring a wider sample and testing them in further research that is not constrained by time. Thus analysing it on a case-by-case basis, and allowing for the creation of a methodology and toolkit to be used would allow for expanded research and exploration of further scenarios (Pustejovsky, 2015).

Background to "EcoHouses" Project and Pilot study

The pilot study was chosen as a proof of concept to the literature mentioned previously, that whilst it is agreed that user behaviour deviates from predicted SAP models, household configuration also impacts that condition (Yao and Steemers, 2005). The premise being that age and employment have a direct

impact on users' routines and thus have an impact on the total energy consumed accordingly. Hence, it was essential to recruit a set of comparable houses in terms of design and construction standards with the variable being the demographic types of users inhabiting it. In addition the research's overall aim is to streamline this process into a simple and affordable methodology that can be performed as part of a routine post-occupancy study thus within the methodology section, a number of low-tech and budget-aware solutions used to start this process and assess their viability.

To satisfy the conditions mentioned above, the researcher approached a set of privately owned houses in Lincoln, UK's Long Leys Urban Village, roughly 1.2 miles from city center. The project; composed of thirteen houses provided a fertile research opportunity due to a number of factors. The houses are built up to code level 5 standard of CfSH (November 2010) using SAP 2009, constructed and partially inhabited by the end of 2014 and, were advertised as eco-housing with low operational costs, self-sustenance and passive house design with a feed-in tariff to entice potential buyers (Elnokaly and A.J. Martin, 2014).

The housing project, located in the East Midlands, is a private development, privately owned by its current residents that were intended to be a step towards sustainable developments by its developer. Built on an area of brown land within a designated urban village within the borders of Lincoln city, the project had to satisfy a high performance rating in order to gain planning permission. The site is composed of thirteen privately owned three and four-bedroom semi-detached houses built using three various layouts and floor areas, but facing the same orientation, built up to the same standard and acquired identical SAP ratings in both design and evaluation stages. The houses studied in this research are built using two of the layouts, labelled B and D in table 1, three and four bedroom houses respectively with identical floorplans in each case. Due to constraints from the developer the exact figures for the second layout were not released, however it was assured that the released SAP rating was identical to the design specifications.

Table 1 As-Designed vs. As-Built

Dwelling type	*As-Designed SAP rating*	*As-Built SAP rating*
Layout B (three bedrooms)	99 (A)	99 (A)
Layout D (four bedrooms)	97 (A)	97 (A)

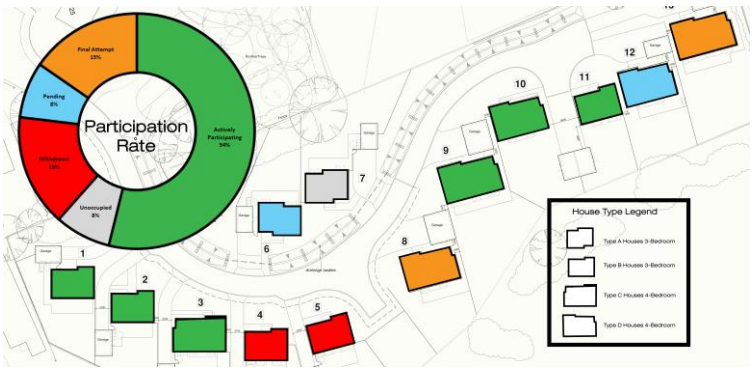

Figure 1 Site and Floor plans and participation rate

The houses were constructed to reduce reliance on main s electricity by providing a calculated 1024.5 kWh of photovoltaic generated electricity per year and 1158.8 kWh of water heating annual that feeds into a combination boiler (SAP Printout, 2015). The house utilizes two systems for heating, a combination boiler of efficiency 88-89.01% and electric underfloor heating (Compliance Report, 2015; SAP Printout, 2015; Vaillant, 2017). The first disperses its heating load through radiator panels distributed throughout the house. It is notable that these panels are their control systems are ill-placed (thermostat is situated close

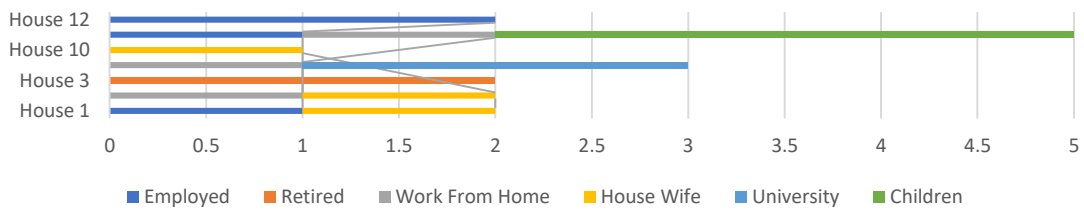

Figure 2. Occupancy and employment values within the case study, from interviews and recruitment

to the panels) causing false-feedback and disturbances within the operation and performance costs of the house. In addition, the houses are occupied by a diverse number of configurations, as shown in fig 2, varying between retired couples, working couples, parents and mixtures of the previous, with a general age range between 40 to mid-sixties. However due to confidentiality, residents' ages are grouped based on NHS age groups within the project.

Methodology

To counter the aforementioned problems, the pilot study of this research project started off by identifying a number of tools, some used previously and others created for this task to generate a large amount of data that can be used within this research to draw relationships and weed out irrelevant and negligible aberrations in behaviour.

The research relies heavily on the research subjects' self-observation of their behaviour and activities through the use of: 1) Daily room occupancy logbooks, 2) Daily activity logbooks, 3) Footfall plan of movement during a typical day, the details of each tool will be further discussed in the following section. The researcher also conducted a number of interviews; based on a modified version of a Building Use Study (CIBSE, 2012) in addition to a number of transcendental phenomenological (Moustakas, 2010) questions that require the users to identify behaviours they routinely or subconsciously partake in. In addition, a bottom up survey of all electric equipment inside the house was performed and mapped on the building's floor plan.

In summary, the research will follow a mixed method research investigation (HO et al., 2006, Cohen et al., 2011). Globally the research will be conducted in the format of an investigative cross-case analysis (Simons, 1996, VanWynsberghe et al., 2008), to ultimately deduce the most prominent factors of user behaviour and how they affect buildings designed using the current UK methodology, SAP under the Code for Sustainable Homes level 5 and compared against data gathered from the Building Use Study and data gathered through this research. Individually, by using empirical data from building performance analysis reports and measurements (Digital Catapult, 2016). Qualitative data gathering through various forms of interview and usage logs (Geer, 1991, Witzel, 2000, Turner, 2010; ElNokaly & Keeling, 2016), and their conversion into comparable and analyzable quantitative values that are to be used within statistical modelling (Dixon-Woods et al., 2005).

However, in addition to gathering a large set of quantitative data, the researcher investigates using a structured interview method with open-ended questions to investigate phenomenological and perception based responses that could account for some of the observed behaviour through logbooks and an experimental procedure. The interview's structure also adopts a modified Building Use Study (BUS) Survey, to extract more perception based question. The research will validate the results obtained from the research-modified interview against the results obtained from the validated results returned by the BUS Methodology group. The BUS methodology has been developed by survey firm Building Use Studies and refined by CIBSE (CIBSE, 1997; CIBSE, 2012). It is used to extract quantitative responses regarding building quality, design and comfort (Pretlove and Kade, 2016). The logbooks are a 30-minute time step chart of activities and room occupancy designed to be filled easily by the participants, they monitor their own activities by filling in the respective time slot, that would be used by the researchers to create a time-plot of probabilistic behaviour and how it would contribute to consumption. The researcher also asked the occupants to participate in an experimental self-observation procedure (Rodríguez et al., 2002; Elnokaly & Martin,2014)), the footfall is marked on a floor plan of their respective houses and given the intensity of lines, the researcher can compare the findings to current occupancy analysis software to identify the gap in assumed versus actual behaviour.

Semi-Structured Interviews

The researcher's first task was to gather demographic, quality of life and transcendental phenomenological information regarding the users' perception of their life and actions in their current dwelling. As well as identify the possible motives behind self-selection of their current dwellings and decisions of probabilistic and planned behavior. The use of a semi-structured interview provides the

benefit of delivering a concise set of questions directed towards gathering data which are both usable for comparison within standardized quality of life surveys such as BUS surveys. Whilst allowing the researcher the freedom to gather subjective knowledge to reflect on the literature and identify limitations and possible avenues for future research. The data also provides the researcher with routine and detailed interactions that are essential to translating logbooks into tables of actions as a method of validation. In addition, recording the users' fixed routines and automated system would serve its purpose in the next phase of this project when translating system operations into energy consumption. The interviews were in the form of a 15 – 30-minute set of questions divided into 1) understanding of the house's sustainable features, 2) Lighting: behaviour and use of artificial lighting, 3) Thermal comfort: self-selection and planned behavioural data regarding their choice of residence and occupancy patterns. Followed by the same questions used within an ARUP BUS survey (CIBSE, 1997; CIBSE, 2012) however following the same grading system and by adding an open-ended response to where the participant has to elaborate in their own words as to why they chose a particular answer.

Some of the scaled data from the structured portion of the interview are shown in figure 2, validating the original claim that user experience varies between the different houses. However, the use of this data can prove to be misleading without support from transcendental phenomenological data such as the background of understanding of these systems, how they were taught to use it, who manages thermal comfort in the house and so on. Quotes from the interviews depicted in Table 2 allows the researcher to assign certain behaviour to lack of knowledge and observe how it changes throughout the study to rule it out as an aberration or a significant impact on building operation. The following excerpts from the interviews gives the research an additional dimension to allow for the analysis of socio-psychological as previously mentioned by gathering transcendental phenomenological data acquired by self-perception of their environment.

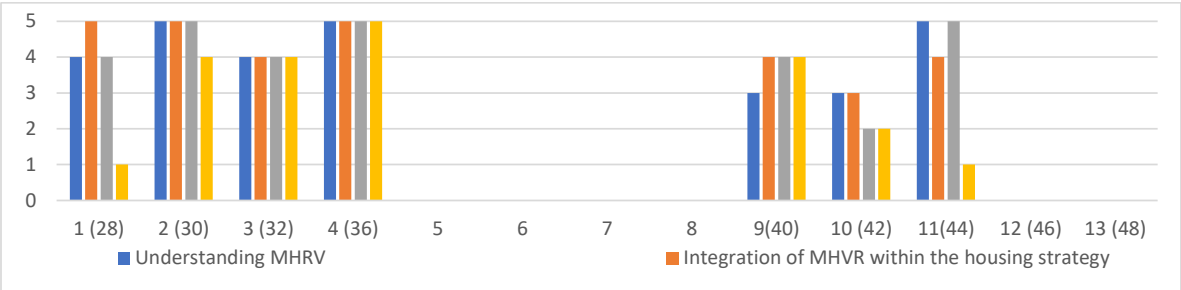

Figure 3 Summary of the house's technology and understanding section of the interview (Researcher's own work)

Table 2 Quotes that support various assumptions and validate information gathered through the logs

How well do you understand the integration of MHRV in the passive strategies & active heating solutions of the house?
"Not well, however my husband maintains all the systems" "We attended a course on operation of eco-houses in Grimsby so we could know the basics of the heating and heat recovery system. We are still not entirely sure how it works but we're learning" "We have only lived here for the duration of one summer so we are not entirely sure how the building performs yet. It was quite warm so we did not need to operate any of the systems"
Time of day when you start turning on the lights?
All houses mentioned that they found that their lighting behaviour depends on real daylight hours, that information was validated by reviewing activity and occupancy logs.
How long have you lived in this house? Is this your first high performance/ecohouse?
"We used to live in a Victorian style house with 5 bedrooms that used to get quite cold and would run up quite a bill for heating. We decided to invest in a house like this hoping to cut down on bills especially now that we live alone after our children moved out" "I used to own another property that was marketed as ecohouse, I moved here to be closer to the city and closer to work"

Occupancy and Activity Log Books

The use of log books relies on users' ability to reflect on their activities and document them within a simple time-step/room sheet. This low-tech affordable approach combines the benefits of easily accessible resources and the need for users to recall their activities to the best of ability. Other methods such as the use of electronic trackers or using phone tracking software are a cause for privacy concerns and possible discomfort, in addition to substantial cost increase, thus they were rejected despite the possible benefits of implementation. The time constraints and man hours involved, however constrained the number of logs to two per month that would be distributed due to the busy lifestyles of the occupants as well as to prevent loss of interest. The users are required to fill two weeks per month of typical behaviour (or atypical behaviour in case of national holidays and visitors) totalling an average set of twenty-four (24) collections per log category per house per year. Upon reviewing the literature and similar research done before, the researcher observed that subjects are not likely to change their activity within one given hour, thus a high resolution profile of activities was neither feasible nor productive in this case. The researcher chose a resolution of 30-minute time-steps, with activities that occupy less than a time-step assessed on a case-by-case basis to identify their impact within the larger picture within the time frame of a single day and the accumulation within a year.

Translating that data from an analogue form to digital was done by the use of an excel sheet using the same headings, however the data was translated by identifying the maximum number of occupants in the house and inserting a corresponding digit to identify the number of occupants within a room or performing a certain task per time-step. By using the following equation, the excel sheet automatically calculates the maximum occupancy in dwelling at a certain time-step, this is required to avoid conflicts that arise due to doing multiple activities within the same interval using $If \sum Occ_{a-e} > Max_n \; Then \; Occupancy = Max_n, \sum Occ < Max_n \; Then \; Occupancy = \sum Occ$ where $\sum Occ_{a-e}$ is the total occupancy count of rooms a-e is. Max_n is the maximum number of occupants known to be available in the house at the time?

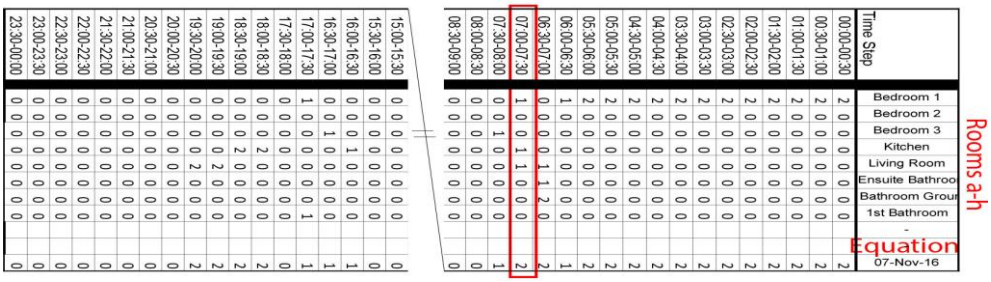

Figure 3 Data Translation procedures through excel sheet. (Researcher's own work)

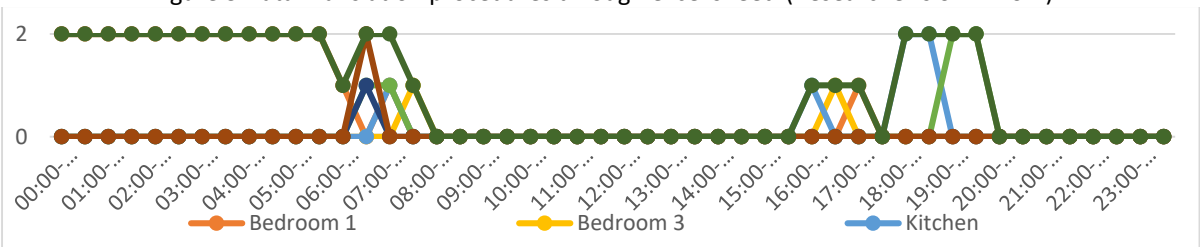

Figure 4 One-day processed data extract through excel sheet of multiple rooms in one dwelling. (Researcher's own work)

Data Loggers

In order to validate the variance in control of the internal environment, the researchers used climatic data loggers placed in key areas of the house, for example, the kitchen and study, which were identified as areas of maximum occupancy. The fluctuations in temperature allow the user to identify environmental cues that influence the occupants' choice to alter internal temperature or trigger any of the automatic systems in place. Currently the research has only monitored one house due to cost and gear restraints. However this has been previously identified as a restraint and additional monitoring equipment has been ordered to continue monitoring the other households. The researcher has used

RHT10 Extech for the first portion of monitoring whilst a requisition for MX1101 (Onsetcomp, 2017) bluetooth data loggers from HOBO was placed part of the development choices after the pilot study.

Conclusion

The pilot phase concluded by April 2017 laying the way for the second phase of this project and continuation of data gathering. The use of activity logs so far has been successful, given the enthusiasm and environmental awareness of occupants, and thus their eagerness to participate in this research. The research team is working on developing a digital method of inputting that data through web-based application as well as self-tracking applications that can be carried mobile for further testing. Data logging is an essential tool and proved to be the highest cost in carrying out this type of research and thus might dissuade others from participating in this kind of research. Extended results of this phase would be published in a later paper, however at this juncture previous hypotheses regarding demographic configurations and their potential impact on consumption have been supported by occupancy and data logger information. Further research is required in order to aggregate these data sets into usable information that can be refined into calculation methodologies as well as the need for expanded research and acquiring of data sets by other researchers to generate a large enough sample for computational analysis. During the handling of the interviews and logbook material, the researcher had to cast away preconceptions of behaviour, adapting Husserl's take on phenomenological research to maintain objectivity of findings (Lowes and Prowse, 2001). Due to the sheer amount of data per household, trends have started to emerge in the form of occupancy patterns, that allow the team to isolate behaviour that is not part of the norm. However, data gathering needs to continue to conclude a year in order to acquire a dataset that is inclusive of different seasonal and climatic changes. Progressing occupancy data to match with consumption data is the next stage since the passive and low-energy devices do not reflect readily with assumed SAP calculations or typical documented behaviour.

References

Ajzen, I. (2011). The Theory of Planned Behaviour. In: P. Van Lange, A. Kruglanski and E. Higgins, ed., Handbook of Theories of Social Psychology: Volume One, 1st ed. pp.438-459.

Ajzen,I. (2011). The theory of planned behaviour: Reactions and reflections. Psychology & Health,26(9),pp.1113-1127.

Blight, T. (2015). Low-Energy Domestic Architecture: The Impact Of Household Behaviour On The Expected Energy Use Of Passive House Dwellings. PhD. University of Bath Department of Architecture and Civil Engineering.

Borden, R. and Schettino, A. (1979). Determinants of Environmentally Responsible Behavior. The Journal of Environmental Education, 10(4), pp.35-39.

BRE and DECC (2014). The Government's Standard Assessment Procedure for Energy Rating of Dwellings.

Build Energy. (2017). The Home Quality Mark Archives - Build Energy. [online] Available at: http://www.buildenergy.co.uk/category/the-home-quality-mark/ [Accessed 10 Jan. 2017].

Compliance Report (2015). Building Regulation Compliance Report. MES Solutions.

Department for Communities and Local Government (2015). Housing Standards Review Summary of Responses.

Digital Catapult (2016) Building data exchange. [online] Available from: http://buildingdataexchange.org.uk/ [Accessed 22 February 2016].

Dixon-Woods, M., Agarwal, S., Jones, D., Young, B., and Sutton, A. (2005) Synthesising qualitative and quantitative evidence: A review of possible methods. J Health Serv Res Policy. 10(1) 45–53B. Available from: http://hsr.sagepub.com/content/10/1/45.short [Accessed 25 February 2016].

Elnokaly, A. and A.J. Martin, B. (2014). The impact of the UK governments spending review into the Feed in Tariff (FIT) on the installation on photovoltaic panels in the residential sector. World Journal of Science, Technology and Sustainable Development, 11(2), pp.102-116.

Elnokaly, Amira and Elseragy, Ahmed (2012) Historic city centres as catalysts for wider sustainable urban regeneration. In: Requalifying the Built Environment: Challenges and Responses. Hogrefe Publishing GmbH Merkelstr. 3, 37085 , Göttingen, Germany. ISBN: 9780889374300

Elnokaly, Amira and Keeling, Ian (2016) An empirical study investigating the impact of micro-algal technologies and their application within intelligent building fabrics. Procedia: Social and Behavioral Sciences, 216. pp. 712-723. ISSN: 1877-0428

Geer, J. G. (1991) Do open-ended questions measure 'salient' issues? Public Opinion Quarterly, 55(3) 360.

Gill, Z., Tierney, M., Pegg, I. and Allan, N. (2010). Low-energy dwellings: the contribution of behaviours to actual performance. Building Research & Information, 38(5), pp.491-508.

GOV (2015). Planning update March 2015 - GOV.UK. [online] Gov.uk. Available at: https://www.gov.uk/government/speeches/planning-update-march-2015 [Accessed 13 Sep. 2016].

Gruber, J. and Prodanovic, M. (2012). Residential Energy Load Profile Generation Using a Probabilistic Approach. 2012 Sixth UKSim/AMSS European Symposium on Computer Modeling and Simulation.

Henderson, J. and BRE (2008). A review of the relationship between floor area and occupancy in SAP. BRE.

HQM and BRE (2015). Home Quality Mark Technical Manual. 2nd ed. [ebook] BRE. Available at: http://www.homequalitymark.com/filelibrary/HQM--December-2015-.pdf [Accessed 12 Feb. 2017].

Kaiser, F. and et al (1996). Environmental Attitude and Ecological Behavior. [online] Available at: http://files.eric.ed.gov/fulltext/ED409179.pdf [Accessed 10 Nov. 2016].

Lowes, L. and Prowse, M. (2001). Standing outside the interview process? The illusion of objectivity in phenomenological data generation. International Journal of Nursing Studies, 38(4), pp.471-480.

Michelson, W. (1977). Environmental choice, human behavior, and residential satisfaction. Nairobi: Oxford.

Moustakas, C. (2010). Phenomenological research methods. 1st ed. Thousand Oaks, Calif: Sage Publications

Onsetcomp (2017). MX1101 | Onset HOBO Data Logger. [online] Onsetcomp.com. Available at: http://www.onsetcomp.com/products/data-loggers/mx1101 [Accessed 12 Dec. 2016].

Oyedele, Lukumon and Regan, Martin and Meding, Jason von and Ahmed, Ashraf and Ebohon, Obas John and Elnokaly, Amira (2013) Reducing waste to landfill in the UK: identifying impediments and critical solutions. World Journal of Science, Technology and Sustainable Development, 10 (2). pp. 131-142. ISSN: 2042-5945

Parys, W., Saelens, D. and Hens, H. (2011). Coupling of dynamic building simulation with stochastic modelling of occupant behaviour in offices – a review-based integrated methodology. Journal of Building Performance Simulation, 4(4), pp.339-358.

Pustejovsky, J. (2015). Measurement-comparable effect sizes for single-case studies of free-operant behavior. Psychological Methods, 20(3), pp.342-359

Pretlove, S. and Kade, S. (2016) Post occupancy evaluation of social housing designed and built to code for sustainable homes levels 3, 4 and 5. Energy and Buildings, 110(January), 120–134.

Richardson, I., Thomson, M., Infield, D. and Clifford, C. (2010). Domestic electricity use: A high-resolution energy demand model. Energy and Buildings, 42(10), pp.1878-1887.

SAP Printout (2015). Full SAP Calculation Printout. MES Building Solutions.Simons, H. (1996) The paradox of case study. Cambridge Journal of Education, 26(2) 225–240.

Tse, P. and Colmer, M. (2014). Innovate UK Building Performance Evaluation: Overview of Programme Portfolio. InnovateUK.Availableat: https://connect.innovateuk.org/documents/3270542/19792080/BPE_ Overview%20of%20the%20programme%2 0portfolio_Nov%202014 [Accessed 13 Apr. 2017].

Turner, D. (2010) Qualitative Interview Design: A Practical Guide for Novice Investigators. The Qualitative Report, 15(3)

Vaillant (2017). Vaillant ecoTEC plus 615 VU GB 156/5-5 Boiler Manual | Plumbing Manuals. [online] Plumbing Manuals. Available at: http://www.plumbingmanuals.com/vaillant-ecotec-plus-615-vu-gb-1565-5-boiler-manual/ [Accessed 16 Apr. 2017].

VanWynsberghe, R. and Khan, S. (2008) Cultivating the under-mined: Cross-case analysis as knowledge mobilizationForum Qualitative Sozialforschung / Forum: Qualitative Social Research

Warren, P. (2014). A review of demand-side management policy in the UK. Renewable and Sustainable Energy Reviews, 29, pp.941-951

Witzel, A. (2000) The Problem-centered InterviewForum: Qualitative Social Research

Yao, R. and Steemers, K. (2005). A method of formulating energy load profile for domestic buildings in the UK. Energy and Buildings, 37(6), pp.663-671.

ZCH (2017). Performance Gap. [online] Zerocarbonhub.org. Available at: http://www.zerocarbonhub.org/current-projects/performance-gap [Accessed 19 Apr. 2017].